LCA Methodology

Calculating the Influence of Alternative Allocation Scenarios in Fossil Fuel Chains

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Abstract

Goal, Scope and Background. As part of an LCA study comparing an average Dutch passenger car running on petrol with a similar car running on bio-ethanol and comparing an average Dutch passenger car running on diesel with a similar car running on biodiesel, the question raised to get more insight into the allocations made in fossil fuel chains in existing databases such as ecoinvent. Both biofuel and fossil fuel chains contain various allocation situations that have been approached differently by various authors leading to differing and incomparable results. For biofuel chains, stakeholders had obtained insight into the allocations in earlier studies, but for the allocations made for the fossil chains, this was not the case. Therefore, one part of the study, which is reported in this paper, focused on a quick scan of different allocation scenarios for fossil fuels chains using the Swiss ecoinvent v1.1 database.

Methods. The quick scan focused on three different allocation scenarios for fossil fuel chains: economic allocation, physical allocation and the ecoinvent default allocation. There appeared to be 54 multi-output (MO) processes linked to both the passenger car and the diesel system in the ecoinvent v1.1 database. Based on contribution analyses identifying which multi-output processes contribute most to one of the environmental impact categories of the characterisation, seven multi-output processes were selected that have been further analysed with the three allocation scenarios mentioned.

Results. The results show that although at the process level allocation factors may differ significantly (up to almost 250), the total results only differ modestly (1–1.5), at least for the present case.

Discussion. There is no general rule between these two. They depend on the scaling factor and the environmental impact related to the resource extractions and emissions of a particular multi-output process and its upstream processes in the total system analysed.

Conclusions. The results of this quick scan are mainly intended for illustrating and learning purposes focusing on the possible influence of different allocation scenarios for fossil fuel chains. Bearing these limitations in mind, it can be concluded that different allocation methods can generate large differences in allocation factors and thus also at the level of environmental impacts allocated to the derived single-output processes. Nevertheless, the aggregated results for the present case only differ modestly.

Keywords: Allocation factor; allocation; ecoinvent database; economic allocation; fossil fuels; life cycle assessment (LCA); multifunctionality; multi-output process; physical allocation

1 Goal, Scope and Background

As part of an LCA study (Hamelinck and Van den Broek 2005) comparing an average Dutch passenger car running on petrol with a similar car running on bio-ethanol and comparing an average Dutch passenger car running on diesel with a similar car running on biodiesel, the question raised to get more insight into the allocations made in fossil fuel chains in existing databases such as ecoinvent. Various stakeholders representing industry, consumers and government were involved in this study, which was primarily intended to increase insight into LCA details for these stakeholders and further to yield understanding on how the environmental performance of biofuels chains is influenced by system choices and could be optimised. Specific data were collected for the LCA calculations on the bio-diesel passenger car, whereas the Swiss ecoinvent v1.1 database (ecoinvent Centre (2004) was used for the LCA of the fossil petrol and diesel passenger car calculations.

In biofuel LCAs, allocation is needed for a number of processes. Comparison of several LCA-studies showed that different allocation methods have been used in earlier studies on bio-fuels (See Broek et al. (2003) for a literature review) and it is generally known within the LCA community that this choice may significantly influence the final results of a particular study (cf. Bernesson et al. 2004). In an LCA, comparing bio-fuels with fossil fuels, one should note that fossil fuel chains also contain various allocation situations, e.g. the refinery, while the allocations made in available databases are often a given fact that cannot be modified anymore. The participants of the study expressed that they would consider the current study to have a real added value to similar existing studies, if they could also gain insights into allocations made for the fossil chains as well. Since the ecoinvent 1.1 database contains a large number of unallocated multi-output processes and therefore in principle allows for calculating different allocation scenarios, it was decided to spend some time to unravel allocations made in this database, in order to enable other allocation choices within these chains as well.

Thus a quick scan LCA has been made elaborating a selected number of allocation scenarios for a selected number of multi-output (MO) processes for an average Dutch passenger car using fossil fuel as modelled in ecoinvent v1.1 for which specific car operation data collected (Hamelinck and Van den Broek 2005). This paper presents an analysis of the differences in results due to three allocation methods: economic allocation, physical allocation and the allocation prin-

ciple that the ecoinvent database takes as a default. Below, first some ecoinvent database issues and the flow chart of the passenger car will be presented. Subsequently, the allocation scenarios and the multi-output processes that have been analysed particularly, are reported and, finally, results and conclusions are presented.

2 Methods

2.1 The database

Some preparatory work had to be performed in order to be able to import the various ecoinvent v1.1 databases needed for this work into the software program used for the calculations: CMLCA (see: http://www.leidenuniv.nl/cml/ssp/index.html). The ecoinvent v1.1 database contains four different sub-databases:

1. A database including all (116) multi-output processes (with default allocation factors) that have thus not yet been allocated.
2. A database including all (2,630) single-output processes, that is (2,355) processes that are single-output by itself and all (275) allocated multi-output processes (allocated with the default allocation factors, which are a mix of economic and physical principles).
3. A database including all aggregated results, that is calculation results (inventory tables) of all products that one can find in the ecoinvent v1.1 database; the individual background processes are not part of this database anymore thus.
4. A database including sets of characterisation factors related to various impact assessment methods.

Database 3 and 4 were of no direct use for our quick scan and we focused on database 1 and 2. **Fig.1** illustrates how database 1 and 2 relate to each other with respect to multi-output processes.

For enabling different allocation choices and calculations, we needed to combine database 1 and 2 by removing the allocated multi-output processes from database 2, because these would otherwise be included twice. Although with some problems, we eventually succeeded to combine database 1 and 2 and were thus able to calculate results. We calculated results for an average Dutch passenger car running on unleaded petrol and an average Dutch passenger car running on diesel as modelled in ecoinvent v1.1. As the results of the petrol and diesel cars are quite comparable for the various allocation scenarios, we here only present the results for the diesel car.

2.2 The flowchart

In **Fig. 2** a part of the flowchart for the operation of an average Dutch passenger (diesel) car has been drafted. It included recursion lines (loops) for processes that are included more than once in this flowchart. To simplify the chart, all capital goods have been excluded and processes have only been included to the third level, otherwise the flowchart would have become too large for this paper.

The total number of processes linked to the 'operation, average Dutch passenger diesel car [NL]' process amounts to 1584. In Fig. 2 only 66 processes are presented for the pragmatic reasons mentioned above.

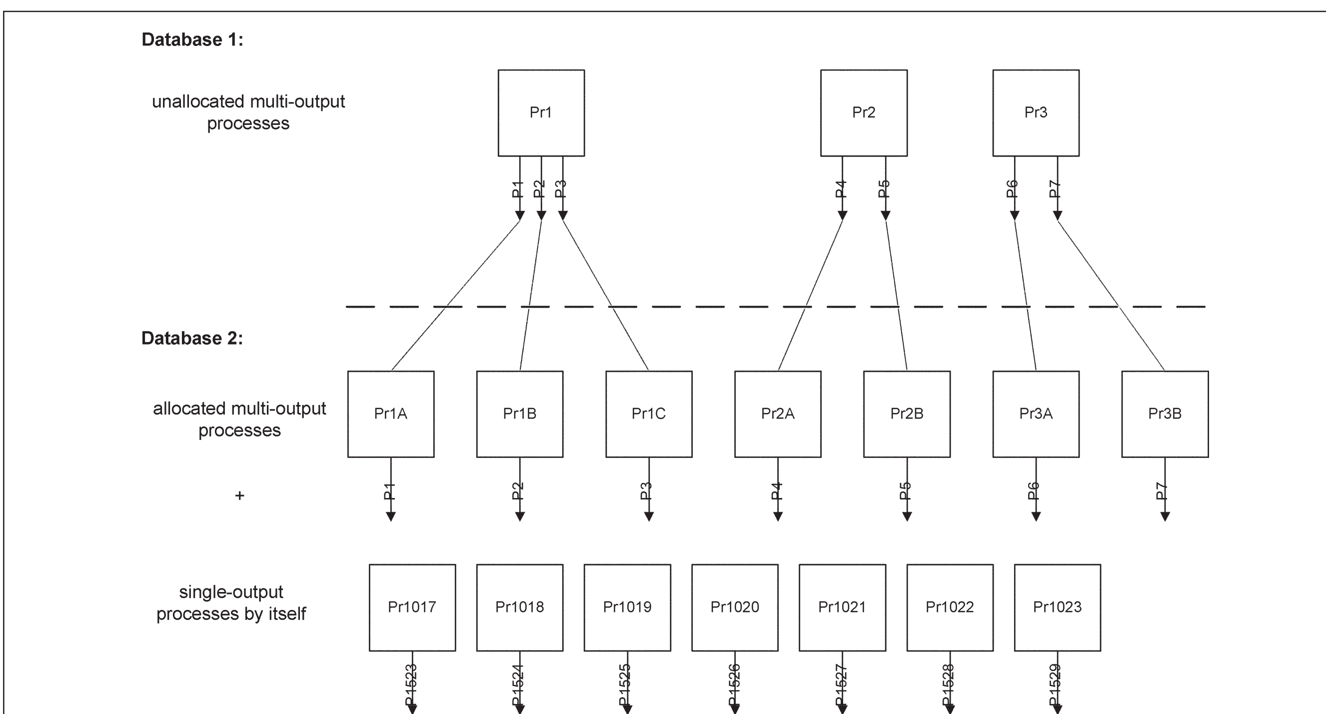

Fig. 1: The relation of ecoinvent database 1 and 2 to each other with respect to multi-output processes (Pr1, Pr1A, etc. refer to certain processes; P1, P2, etc. refer to certain products)

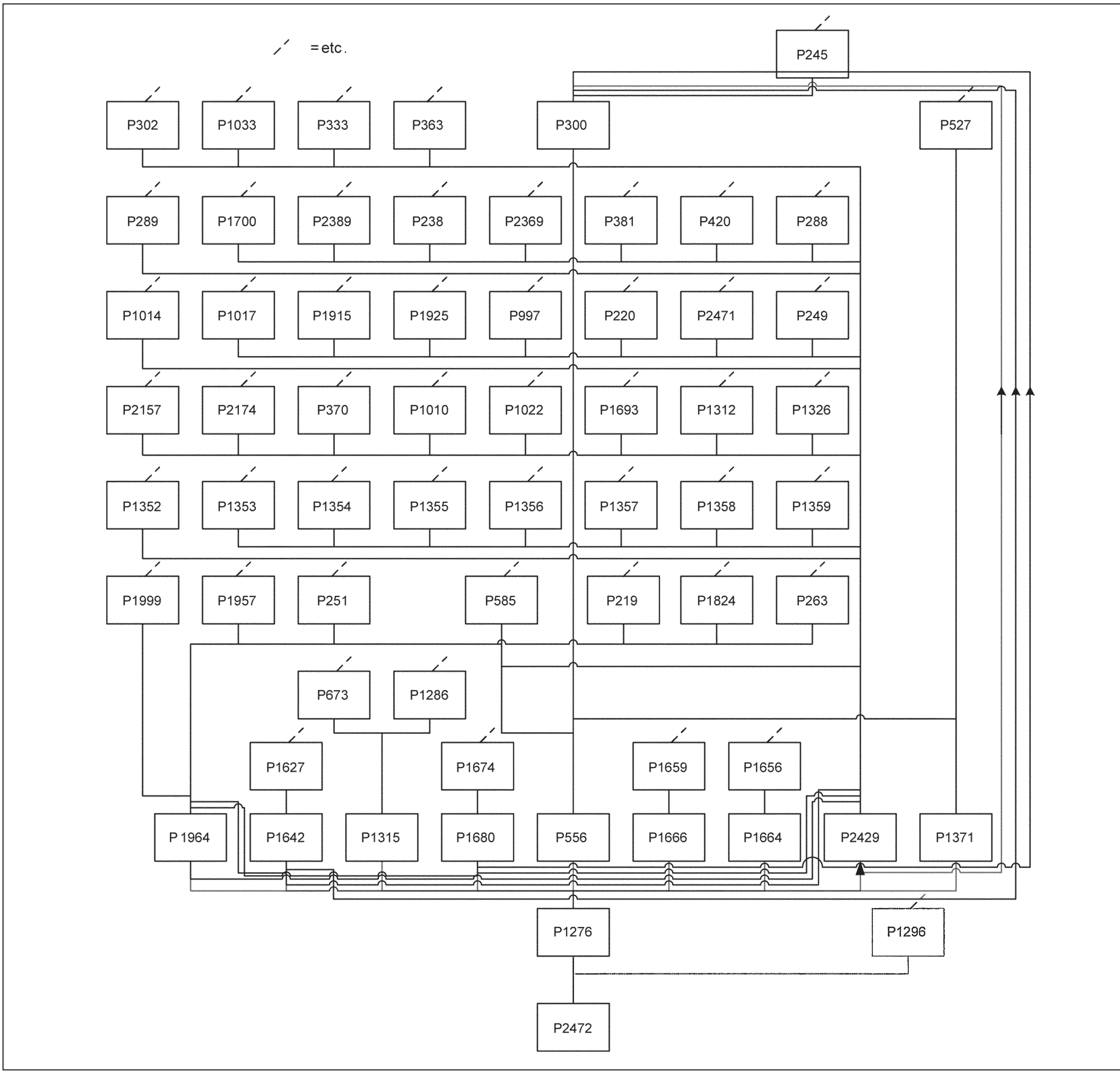

Fig. 2: Simplified and partial flowchart for 1 km operation of an average Dutch passenger (diesel; P2472) car as modelled in ecoinvent v1.1 using specific Dutch car driving emission and fuel consumption data (Hamelinck and Van den Broek 2005). All flows go top-down unless otherwise indicated. Dashed lines indicate connections with higer order processes

2.3 Multi-output processes and allocation scenarios selected

The allocation scenarios have been limited to the following three:

1. Economic value (economic allocation): in this scenario calculations are performed on the basis of the proceeds (quantity produced times price per quantity) of the valuable outputs of the multi-output process (Guinée et al. 2004).
2. Common physical parameter (physical allocation): in this scenario calculations are performed on the basis of a common physical parameter of the valuable outputs of the multi-output process. In this quick scan, the common physical parameter will be mass (kg) or energy content (MJ). If for a specific multi-output process a common physical parameter cannot be determined or derived, economic allocation will be applied again for that process.
3. ecoinvent default allocation: in this scenario the allocations are taken as currently implemented in the ecoinvent v1.1 database by its designers. The ecoinvent default allocation includes differentiated allocation factors (not just one for all inputs and outputs as in allocation scenario 1. and 2. above) based on physical-causal relationships, common physical parameters (mass or heating value) and/or the economic proceeds of the valuable outputs of the multi-output process after, where possible, processes have been split up in order to avoid allocation (Jungbluth et al. 2005).

Table 1: Explanation of P-numbers used in Fig. 2. The fourth column indicates whether a process is a multi-output (MO) process or not. In this simplified and partial flowchart only 4 multi-output processes are included, whereas the complete flowchart of the system includes 54 multi-output processes (see section 2.3)

P-no.	Process name	ecoinvent EI-ID no.	MO
[P219]	Aluminium sulphate, powder, at plant [RER]	245	–
[P220]	Ammonia, liquid, at regional storehouse [RER]	246	–
[P238]	Chlorine, liquid, production mix, at plant [RER]	269	–
[P245]	Fluorine, liquid, at plant [RER]	276	–
[P249]	Hydrochloric acid, 30% in H_2O, at plant [RER]	282	–
[P251]	Hydrogen peroxide, 50% in H_2O, at plant [RER]	284	–
[P263]	Ozone, liquid, at plant [RER]	302	–
[P288]	Sodium hydroxide, 50% in H_2O, production mix, at plant [RER]	336	–
[P289]	Sodium hypochlorite, 15% in H_2O, at plant [RER]	337	–
[P300]	Sulphur hexafluoride, liquid, at plant [RER]	348	–
[P302]	Sulphuric acid, liquid, at plant [RER]	350	–
[P333]	Chemicals organic, at plant [GLO]	382	–
[P363]	Lubricating oil, at plant [RER]	416	–
[P370]	Methyl tert-butyl ether, at plant [RER]	425	–
[P381]	Propylene glycol, liquid, at plant [RER]	438	–
[P420]	Lime, hydrated, packed, at plant [CH]	487	–
[P527]	Electricity, high voltage, production UCTE, at grid [UCTE]	606	–
[P556]	Electricity, low voltage, production UCTE, at grid [UCTE]	635	–
[P585]	Electricity, medium voltage, production UCTE, at grid [UCTE]	664	–
[P673]	Electricity, low voltage, at grid [CH]	752	–
[P997]	Iron sulphate, at plant [RER]	1102	–
[P1010]	Molybdenum, at regional storage [RER]	1116	–
[P1014]	Palladium, at regional storage [RER]	1127	–
[P1017]	Platinum, at regional storage [RER]	1133	–
[P1022]	Rhodium, at regional storage [RER]	1142	–
[P1033]	Zinc for coating, at regional storage [RER]	1156	–
[P1276]	Diesel, at regional storage [RER]	1543	–
[P1286]	Light fuel oil, at regional storage [CH]	1559	–
[P1294]	Petrol, two-stroke blend, at regional storage [RER]	1569	–
[P1296]	Petrol, unleaded, at regional storage [RER]	1573	–
[P1312]	Heavy fuel oil, burned in refinery furnace [RER]	1594	–
[P1315]	Light fuel oil, burned in boiler 100kW, non-modulating [CH]	1597	–
[P1326]	Refinery gas, burned in furnace [RER]	1608	–
[P1352]	Crude oil, production GB, at long distance transport [RER]	1641	–
[P1353]	Crude oil, production NG, at long distance transport [RER]	1643	–
[P1354]	Crude oil, production NL, at long distance transport [RER]	1644	–
[P1355]	Crude oil, production NO, at long distance transport [RER]	1645	–
[P1356]	Crude oil, production RAF, at long distance transport [RER]	1646	–
[P1357]	Crude oil, production RLA, at long distance transport [RER]	1647	–
[P1358]	Crude oil, production RME, at long distance transport [RER]	1648	–
[P1359]	Crude oil, production RU, at long distance transport [RER]	1649	–
[P1371]	Transport, crude oil pipeline, onshore [RER]	1662	–
[P1627]	Operation, lorry 32t [RER]	1926	–
[P1642]	Transport, lorry 32t [RER]	1943	–
[P1656]	Operation, barge tanker [RER]	1959	–
[P1659]	Operation, transoceanic tanker [OCE]	1962	–
[P1664]	Transport, barge tanker [RER]	1967	–
[P1666]	Transport, transoceanic tanker [OCE]	1969	–
[P1674]	Operation, freight train [RER]	1977	–
[P1680]	Transport, freight, rail [RER]	1983	–
[P1693]	Zeolite, powder, at plant [RER]	1996	–
[P1700]	Soap, at plant [RER]	2003	–
[P1824]	Disposal, wood untreated, 20% water, to municipal incineration [CH]	2130	–
[P1915]	Disposal, refinery sludge, 89.5% water, to sanitary landfill [CH]	2237	–
[P1925]	Disposal, catalytic converter NOx reduction, 0% water, to underground deposit [DE]	2249	–
[P1957]	Treatment, sewage, unpolluted, to wastewater treatment, class 3 [CH]	2281	–
[P1964]	Tap water, at user [RER]	2288	–
[P1999]	Charcoal, at plant [GLO]	2347	–
[P2157]	Naphtha, at regional storage [RER]	5720	–
[P2174]	Refinery gas, burned in flare [GLO]	5747	–
[P2369]	Air separation, cryogenic [RER]	14	+
[P2389]	Nickel production, sulphidic ore, primary [GLO]	35	+
[P2429]	Crude oil, in refinery [RER]	75	+
[P2471]	Soda production, solvay process, at plant [RER]	121	+
[P2472]	Operation, passenger petrol car [Ecofys] [NL]	–	–

Sources: ecoinvent v1.1.; Hamelinck and Van den Broek, 2005
DE = Germany; OCE = Oceanic; UCTE = Union for the Co-ordination of Transmission of Electricity; RER = Europe; NL = Netherlands; GLO: = Global; CH = Switzerland

Table 2: Multi-output processes selected for further analysis according to three allocation scenarios (economic allocation, physical allocation and ecoinvent default allocation)

P-no.	Name	ecoinvent EI-ID no.
[P2390]	Platinum group metal production, primary [ZA]	36
[P2391]	Platinum group metal production, primary [RU]	37
[P2422]	Combined offshore gas and oil production [NO]	68
[P2429]	Crude oil, in refinery [RER]	75
[P2430]	Combined gas and oil production [NG]	76
[P2431]	Combined offshore gas and oil production [GB]	77
[P2432]	Municipal solid waste to municipal incineration [CH]	78

ZA = South Africa; RU = Russian Federation; NO = Norway; RER = Europe; NG = Nigeria; GB = United Kingdom; CH = Switzerland

There are 54 multi-output processes linked to the joint passenger car and diesel system in the ecoinvent v1.1 database. Within this quick scan, it is impossible to run the three allocation scenarios for all 54 multi-output processes and to collect price data for these etc. Therefore, contribution analyses have first been performed on the passenger car results using the default ecoinvent allocation determining which multi-output processes contribute most to one of the environmental impact categories of the characterisation (abiotic depletion, global warming, etc.). This has resulted to a selection of seven multi-output processes that have been further analysed with the three allocation scenarios mentioned above (**Table 2**).

Note, however, that none of these seven multi-output processes contributed for more than 5% to one of the environmental impact category totals, except for abiotic depletion where the contribution of multi-output processes to the totals approached 50%.

For these seven multi-output processes the three allocation scenarios have been calculated. Following as much as possible the guidelines reported by Guinée et al. (2002), price data have been collected through public sources as the CBS statistics and all kinds of relevant websites. The price data used for the economic allocation scenarios and the sources used for this are presented in **Annex 1** (see p. 8).

2.4 Impact assessment

The inventory results were further processes with a characterization step. For this, the CML recommended baseline impact assessment method (Guinée et al. 2002) was applied, including the following impact categories and characterisation factors (**Table 3**).

3 Results and Discussion

Below, results will be presented in terms of:

- allocation factors (determining the part of economic inputs, resource extractions, emissions etc. that is allocated to each of the valuable outputs of a multi-output process) for each of the three allocation scenarios;
- impact assessment (characterisation) results for each of the three allocation scenarios (economic, physical and ecoinvent default allocation) for 1 km driving (operation of an average Dutch passenger diesel car) using the ecoinvent v1.1 database.

3.1 Allocation factors (expressed in %) for selected multi-output processes for three different allocation scenarios

Table 4 shows that different allocation methods may result in quite diverging sets of allocation factors. The most extreme differences are found for the *[P2390] platinum group metal production, primary [ZA]* multi-output process. Here, mass allocation or economic allocation changes the allocation factors for platinum from 0.003 to almost 0.7[1]. For other processes the changes are less substantial.

[1] It may be clear that for this specific process mass allocation is not appropriate as it does not reflect at all the reasons for the existence of this process. Still some authors argue that mass allocation is the 'least problematic approach to use' (Sheehan et al. 1998).

Table 3: Impact categories and characterisation factors applied (Guinée et al. 2002)

Impact category	Characterisation factor
Depletion of abiotic resources	Abiotic Depletion Potential (ADP)
Climate change	Global Warming Potential (GWP_{100})
Stratospheric ozone depletion	Ozone Depletion Potential (ODP_{∞})
Human toxicity	Human Toxicity Potential (HTP_{∞})
Freshwater aquatic ecotoxicity	Freshwater Aquatic Ecotoxicity Potential ($FAETP_{\infty}$)
Marine aquatic ecotoxicity	Marine Aquatic Ecotoxicity Potential ($MAETP_{\infty}$)
Terrestrial ecotoxicity	Terrestrial Ecotoxicity Potential ($TETP_{\infty}$)
Photo-oxidant formation	Photochemical Ozone Creation Potentials (high NO_x POCP)
Acidification	Acidification Potential (AP; based on RAINS)
Eutrophication	Eutrophication Potential (EP)

Table 4: Allocation factors for three allocation scenarios: economic, physical and ecoinvent default allocation

Products	Economic allocation	Physical allocation	ecoinvent default allocation
Process = [P2390] platinum group metal production, primary [ZA] [a]			
Palladium, primary, at refinery [ZA]	18.8%	0.1%	18.8%
Platinum, primary, at refinery [ZA]	65.8%	0.3%	65.8%
Rhodium, primary, at refinery [ZA]	7.2%	0.0%	7.2%
Copper, primary, from platinum group metal production [ZA]	1.4%	41.3%	1.4%
Nickel, primary, from platinum group metal production [ZA]	6.8%	58.3%	6.8%
Process = [P2391] platinum group metal production, primary [RU] [a]			
Palladium, primary, at refinery [RU]	21.0%	0.0%	21.0%
Platinum, primary, at refinery [RU]	10.7%	0.0%	10.7%
Rhodium, primary, at refinery [RU]	1.9%	0.0%	1.9%
Copper, primary, from platinum group metal production [RU]	19.4%	58.1%	19.4%
Nickel, primary, from platinum group metal production [RU]	46.9%	41.9%	46.9%
Process = [P2422] combined offshore gas and oil production [NO] [b]			
Natural gas, at production offshore [NO]	33.3%	20.7%	20.7%
Crude oil, at production offshore [NO]	66.7%	79.3%	79.3%
Process = [P2429] crude oil, in refinery [RER] [c]			
Naphtha, at refinery [RER]	8.0%	6.5%	6.5%
Heavy fuel oil, at refinery [RER]	9.7%	16.8%	16.8%
Petroleum coke, at refinery [RER]	0.0%	0.0%	0.0%
Secondary sulphur, at refinery [RER]	0.1%	0.5%	0.5%
Propane/ butane, at refinery [RER]	2.3%	2.7%	2.7%
Bitumen, at refinery [RER]	0.0%	0.1%	0.1%
Diesel, at refinery [RER]	13.9%	9.6%	9.6%
Kerosene, at refinery [RER]	3.7%	6.4%	6.4%
Light fuel oil, at refinery [RER]	26.1%	25.6%	25.6%
Petrol, unleaded, at refinery [RER]	27.8%	20.6%	20.5%
Refinery gas, at refinery [RER]	8.0%	11.2%	11.2%
Electricity, at refinery [RER]	0.5%	0.0%	0.0%
Process = [P2430] combined gas and oil production [NG] [b]			
Crude oil, at production [NG]	83.1%	90.4%	90.4%
Natural gas, at production [NG]	16.9%	9.6%	9.6%
Process = [P2431] combined offshore gas and oil production [GB] [b]			
Natural gas, at production offshore [GB]	51.4%	35.7%	35.7%
Crude oil, at production offshore [GB]	48.6%	64.3%	64.3%
Process = [P2432] municipal solid waste to municipal incineration [CH] [d]			
Disposal, municipal solid waste, 22.9% water, to municipal incineration [CH]	65.4%	65.4% *	100.0%
Electricity from waste, at municipal waste incineration plant [CH]	11.0%	11.0% *	0.0%
Heat from waste, at municipal waste incineration plant [CH]	23.6%	23.6% *	0.0%

* For this specific multi-output process a common physical parameter cannot be determined or derived, and therefore economic allocation has been applied here again.

[a] Physical allocation for this process is based on the mass, whereas ecoinvent default allocation is based on the economic proceeds of the products of the multi-output process. The allocation factors for the 'ecoinvent default allocation' scenario are different from those reported in ecoinvent Centre (2004), report No. 10, Section 5.1.2 as the latter appeared to be erroneous (see http://www.ecoinvent.ch/download/errors_v1.1.pdf).

[b] Physical allocation and ecoinvent default allocation are both based on the heating values of the products of the multi-output process.

[c] Physical allocation and ecoinvent default allocation are both based on the mass of the products of the multi-output process. For some specific flows, ecoinvent has applied other allocation rules resulting in very small differences (that almost disappear completely when rounding-off) between the results of the 'physical allocation' and 'ecoinvent default allocation' scenarios.

[d] For this specific multi-output process, a common physical parameter cannot be determined or derived, and therefore economic allocation has also been applied for the 'physical allocation scenario'.

Finally note that ecoinvent didn't allocate any impacts to the co-production of electricity and heat in process *[P2432] municipal solid waste to municipal incineration [CH]*.

3.2 Environmental impacts of average Dutch passenger diesel car for three different allocation scenarios

The results for 1 km driving with an average Dutch passenger diesel car are shown in **Table 5**.

These impact assessment (characterisation) results above show that although at the process level allocation factors may show huge differences (up to almost 250), the total results only differ modestly (1–1.5; see 2nd and 3rd columns), at least for the present case. There is no general rule between these two. They depend on the scaling factor and the (direct and indirect) environmental impact related to a particular multi-output process. For example, if the *[P2390]*

Table 5: Impact assessment (characterisation) results for 1 km driving with an average Dutch passenger diesel car for each of the three allocation scenarios (economic, allocation and ecoinvent default allocation). All results are presented relative to the 'ecoinvent allocation' results

	Economic allocation	Mass allocation	ecoinvent allocation
Impact category			
Abiotic depletion	1.3	1.0	1.0
Global warming	1.1	1.0	1.0
Ozone layer depletion	1.4	1.0	1.0
Human toxicity	1.5	1.1	1.0
Freshwater aquatic ecotoxicity	1.5	1.0	1.0
Marine aquatic ecotoxicity	1.4	1.0	1.0
Terrestrial ecotoxicity	1.5	1.0	1.0
Photochemical oxidation	1.3	1.0	1.0
Acidification	1.4	1.0	1.0
Eutrophication	1.1	1.0	1.0
1,4-DCB = 1,4-dichlorobenzene			

platinum group metal production, primary [ZA] process quantitatively only plays a very marginal role in the operation of an average Dutch passenger diesel car, then a huge difference in allocation factors will only give a minor change in the total result. However, if e.g. a very hazardous chemical emission would be involved in that process, the change in the total result could be more significant.

4 Conclusions

Before conclusions are presented, it is important to note that we have made no efforts to assess the representativeness and the general quality of the contents of the ecoinvent v1.1 database. For this exercise, we have taken it as it is. Moreover, the conclusions are only valid for the case-study of this paper and cannot simply be generalized.

Bearing these limitations in mind, the following conclusions can be drawn from this quick scan LCA on three different allocation scenarios for the passenger car fossil fuel chain using the ecoinvent v1.1 database:

- Different allocation methods can generate large differences in allocation factors for individual processes and thus also at the level of environmental impacts allocated to the derived single-output processes (differences up to a factor of almost 250 have been observed).
- Despite the point made in the first bullet, different allcoation methods can have quite limited differences in the LCIA results of entire product systems. For this specific passenger car case-study, the differences remain within a factor 1.5. This is due to the fact that the total result depends on the scaling factor and the environmental impact related to the resource extractions and emissions of a particular multi-output process and its upstream processes in the total system analysed, or in other words, it depends on the importance of that particular MO-process in the whole passenger car system. These scaling factors and impacts were relatively small for the seven multi-output processes in this quick scan.

The results are mainly intended for illustrating and learning purposes focusing on the possible influence of different allocation scenarios for fossil fuel chains. Besides other parameters, price data may influence the results. In this case the price data on the refinery products are the most important ones, as the influence of the other multi-output processes on the final results is marginal. As the system wide effect of choosing between economic allocation and mass allocation has shown to be small in the present case-study, it is obvious that deviations in price data will have an even smaller effect. However, in a different case-study, these effects might well be larger. A systematic sensitivity analysis as part of the interpretation phase remains necessary.

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Annex 1: Price data used for the economic allocation scenario

Process	Economic outflow	Unit	Price (€/unit)	Source	Density	Unit	Source
Platinum group metal production, primary [ZA or RU]	Palladium, primary, at refinery	kg	9420*	ecoinvent report No. 10: Life Cycle Inventories of Metals			
	Platinum, primary, at refinery	kg	14018*	ecoinvent report No. 10: Life Cycle Inventories of Metals			
	Rhodium, primary, at refinery	kg	30704*	ecoinvent report No. 10: Life Cycle Inventories of Metals			
	Copper, primary, from platinum group metal production	kg	1.99*	ecoinvent report No. 10: Life Cycle Inventories of Metals			
	Nickel, primary, from platinum group metal production	kg	6.65*	ecoinvent report No. 10: Life Cycle Inventories of Metals			
Combined offshore gas and oil production [NO, NG or GB]	Natural gas, at production offshore	Nm^3	0.37	http://statline.cbs.nl; oil world market	0.78	kg/m^3	ecoinvent report no. 6 – Part V: natural gas
	Crude oil, at production offshore	kg	0.23	http://statline.cbs.nl; oil world market	860	g/l	ecoinvent report no. 6 – Part IV: crude oil
Crude oil, in refinery [RER]	Naphtha, at refinery [RER]	kg	0.32				
	Heavy fuel oil, at refinery [RER]	kg	0.15				
	Petroleum coke, at refinery [RER]	kg	0.01				
	Secondary sulphur, at refinery [RER]	kg	0.05	http://www.icislor.com/il_shared/Samples/SubPage152.asp			0.00
	Propane/ butane, at refinery [RER]	kg	0.22				
	Bitumen, at refinery [RER]	kg	0.09	http://news.tradingcharts.com/futures/3/8/63354383.html	1025	g/l	ecoinvent report no. 6 – Part IV: crude oil
	Diesel, at refinery [RER]	kg	0.38	0,37 €/l taxes excluded	0.84	kg/l	ecoinvent report no. 6 – Part IV: crude oil
	Kerosene, at refinery [RER]	kg	0.15				
	Light fuel oil, at refinery [RER]	kg	0.27				
	Petrol, unleaded, at refinery [RER]	kg	0.35	0.68 €/l taxes excluded	0.75	kg/l	ecoinvent report no. 6 – Part IV: crude oil
	Refinery gas, at refinery [RER]	kg	0.19	Assumption: 50% of gas price			
	Electricity, at refinery [RER]	kWh	0.06				
Municipal solid waste to municipal incineration [CH]	Disposal, municipal solid waste, 22.9% water, to municipal incineration [CH]	kg	0.10	http://www.rivm.nl/milieuennatuurcompendium/nl/i-nl-0428-04.html			
	Electricity from waste, at municipal waste incineration plant [CH]	kWh	0.06				
	Heat from waste, at municipal waste incineration plant [CH]	MJ	0.02	Assumption: price waste heat equals price waste electricity, calculated from kWh to MJ (factor 3.6)			

* In US$/unit